

## 2012 International Symposium on Safety Science and Technology Experimental study on the response characteristics of photoelectric smoke detectors below grid ceilings of different hollowing rate

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### Abstract

There are many differences on the setting requirements of fire detectors in the buildings used grid or flat ceilings. In this paper, applied researches on the setting standard of fire detector below grid ceilings were firstly carried out. On the basis of the setting requirements of fire detector, the numerical simulation of smoke movement below and above grid ceilings with four kinds of hollowing rates was conducted in the standard combustion lab by using FDS software. After that, according to the GB4715-2005 National Standard's sensitivity requirements of the 75mm×75mm size grid ceilings, the experimental researches on the response characteristics of photoelectric smoke detectors, which were above or under the grid ceilings, were carried out under conditions of different obscuration rates and in FDS simulations. Finally, through comparative analysis of the experimental study and numerical simulation results, the correctness of numerical simulations and the feasibility of using FDS to study the smoke spread below and above grid ceilings were validated.

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**Keywords:** fire detector; grid ceiling; hollowing rate; smoke spread characteristic

### 1. Introduction

With the development of economy, the function, type, structure and application environment of architecture are becoming more and more complex. And grid ceilings are usually selected to place the ventilation ducts and electric cables of central air-conditioning system. However, due to the low fire resistance, when the ceiling is subjected to fire attack, the supporting structure would collapse easily and combustible ceiling insulation material would be ignited, the flame will spread along the ventilation ducts so that the fire in the ceiling quickly spread. Since the grid ceilings have great fire risks, photoelectric smoke detectors must be installed in such places.

Grid ceilings in buildings have many forms, but the installation of photoelectric smoke detectors do not have the requirements in our related standards, and it is difficult for the fire department to design, supervise and inspect. So the installations of fire detector are different for different places, on the grid ceilings or building roofs. This will lead to some problems. On the one hand, detectors can't realize early detection and may have blind spots. On the other hand, full coverage of detectors will lead to large investment and financial waste.

The study on fire detection technology is earlier carried out in developed country, such as the United States standard NFPA 72[1] and the British standard BS 5839.1[2]. However, the above standards' requirements on the installations of fire detector in grid ceilings do not comprehensive and detailed enough so that it can not meet the current need in our country.

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Therefore, it is of great practical significance and in line with the fire career and market demand to carry out the study on the design and installation technology of fire detector in grid ceilings.

## 2. Numerical simulation of smoke in grid ceilings

The length of standard combustion chamber for detecting fire detector's performance is 9m-11m; its width is 6m-8m; its height is 3.8m-4.2m<sup>[3]</sup>. Consequently, the paper uses the 10m×7m×4m size laboratory; fire source is in the center of floor and the grid ceiling hangs below the roofs, as shown in Fig 1.

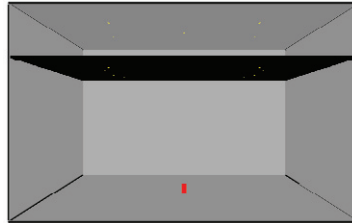


Fig. 1. The simulation charts of standard chamber with grid ceilings.

With the temperature holding on 600°C, radiant intensity keeping on 20 KW/m<sup>2</sup>, cone calorimeter was experimented in the standard combustion chamber. And the results showed that the average heat-releasing speed of beech fire source is 90.93kW/m<sup>2</sup>, and the fire source's HRRPUA is 90.93 in the FDS instance.

The grid ceiling in 75 mm×75 mm size was designed (height is 40mm, width is 10mm, hollowing rate is 75%) as the basic model. With blocks of different dimensions, decreasing hollowing rates of 15%, 30%, 75% and 100%, and suspending height 1m, blocks' setting-up means in different hollowing rate are listed in Table 1, the hollowing simulation chart is shown in Fig 2. The flow of smoke<sup>[4]</sup> for each of the four kinds of hollowing rate at the time of 300s is shown in Fig 3.

Table 1. Four kinds of the hollowing rates conformation means table

Ceiling categories	Form manner		
	Blocks' width	Shelter manners	Hollowing rate in fact
Hollowing rate 15%	80mm and 40mm	Along long side each grid alternate shelter	14.60%
Hollowing rate 30%	40mm	Along long side each grid shelter	29.21%
Hollowing rate 75%	No blocks	No shelter	75.14%
Hollowing rate 100%	No suspended ceilings	No shelter	100%

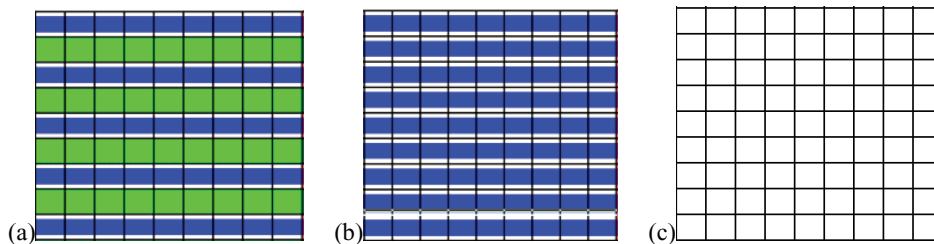


Fig. 2. Hollowing simulation charts for (a)15% hollowing rate, (b) 30% hollowing rate and (c) 75% hollowing rate.

The smoke plume vertical upward would form ambulatory "ceiling jet" along the building roof and the grid suspended ceiling because it is blocked doubly by building roof and suspended ceiling. Plume approximately shows circular and its brim is not too thick. Smoke would move around along roof and suspended ceiling when it runs up to some thickness. With the 15% hollowing rate, smoke plume is blocked more seriously during the ascending course, "ceiling jet" mainly forms below suspended ceiling; the suspended ceiling with 30% hollowing rate can only block small portions of the smoke plume, so it can't form "ceiling jet" under the suspended ceiling; the suspended ceiling with 75% hollowing rate almost makes no impact for smoke plume to blow through grid suspended ceiling, and "ceiling jet" mainly forms on building roof; it is the

real "ceiling jet" when there is no suspended ceiling in the simulation environment. The visibility slices<sup>[4]</sup> of suspended ceiling and building roof plane for each of the four kinds of hollowing rates at the time of 300s are respectively shown in Fig 4 and Fig 5.

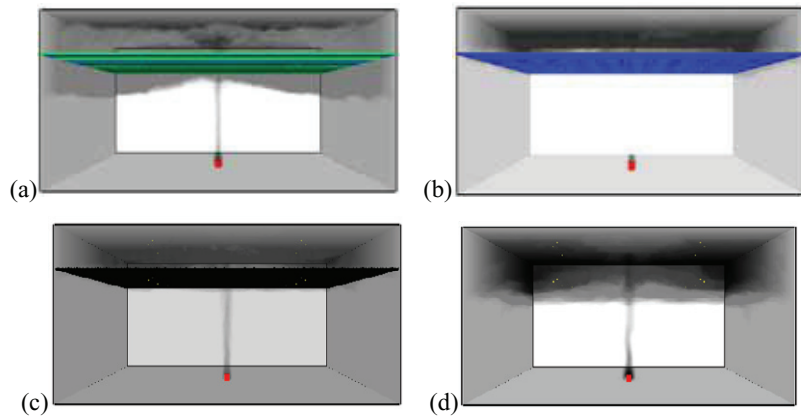


Fig. 3. The flow of smoke in (a) 15%, (b) 30%, (c) 75% and (d) 100% hollowing conditions at the time of 300s.

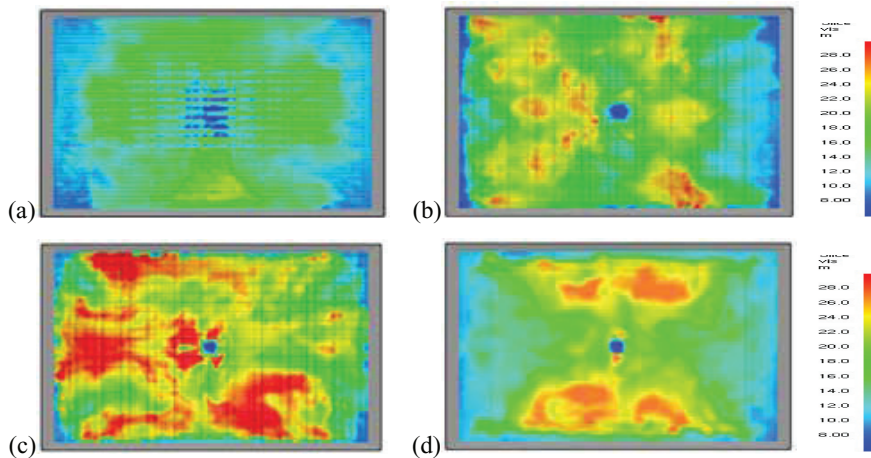


Fig.4 The visibility slices of grid suspended ceiling plane in (a) 15%, (b) 30%, (c) 75% and (d) 100% hollowing conditions at the time of 300s.

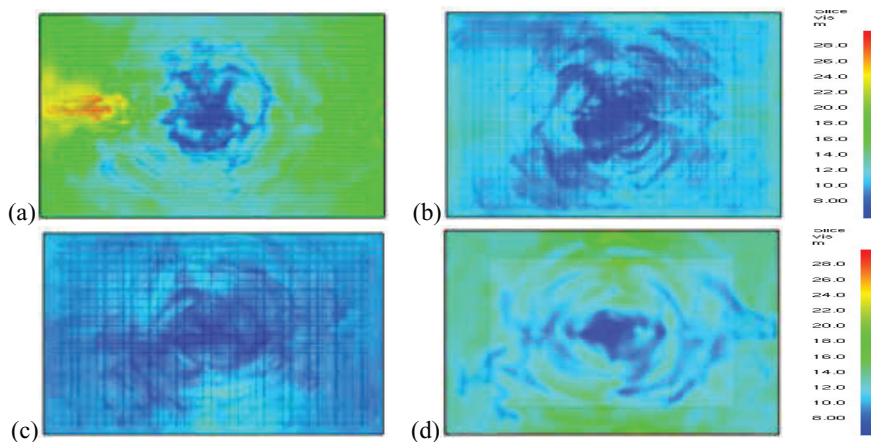


Fig. 5. The visibility slices of building roof plane in (a) 15%, (b) 30%, (c) 75% and (d) 100% hollowing conditions at the time of 300s.

It is shown that on suspended ceiling plane, the visibility slices of 15% hollowing rate is the minimum, while 100% hollowing rate is the maximum; on building roof plane, the flow of smoke that moves up to the building roof is affected and inhaled by suspended ceiling. A part of the smoke plume could "rebound" to the building roof, and the suspended ceiling would reduce the flow of smoke as the hollowing rate increases. So the visibility slices of 100% hollowing rate on the building roof plane is a little larger than 30% and 75% hollowing conditions.

Testing dots numbered 1#-8# are intercalated equably in the circle, center of the building-roof, and the radius is 3m. Similarly, other testing dots numbered 21#-28# are intercalated on the corresponding locality of the suspended ceiling plane, as shown in Fig 6.

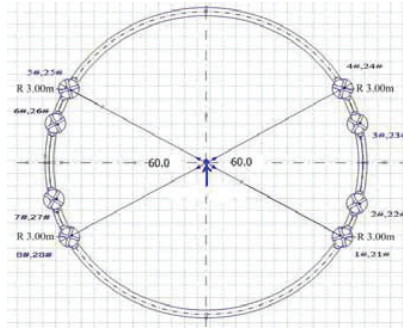


Fig. 6. The locality of testing dots.

The extinction coefficient curve of three testing dots below suspended ceiling and building roof for each of the four kinds of hollowing rate are shown in Fig 7 and Fig 8. In general, as hollowing rate increases, the time when smoke is detected by each testing dot below suspended ceiling increases, while the time below building roof reduces; when there is no suspended ceiling (100% hollowing rate), because smoke would not be blocked during the course of subsiding, the time when smoke is detected below the suspended ceiling in 100% hollowing rate condition is quicker than the time of 75% hollowing rate. On the other hand, at the early stage of the same time, the smaller hollowing rate leads to larger extinction coefficient below suspended ceiling, but smaller extinction coefficient below building roof. As the simulation continues, extinction coefficient for each of the four kinds of hollowing rate goes a line. This shows that the smaller hollowing rate at the early stage, the larger smoke concentration below suspended ceiling and the smaller smoke concentration below building roof. As the smoke increases, the smoke concentration above and below suspended ceiling goes a line.

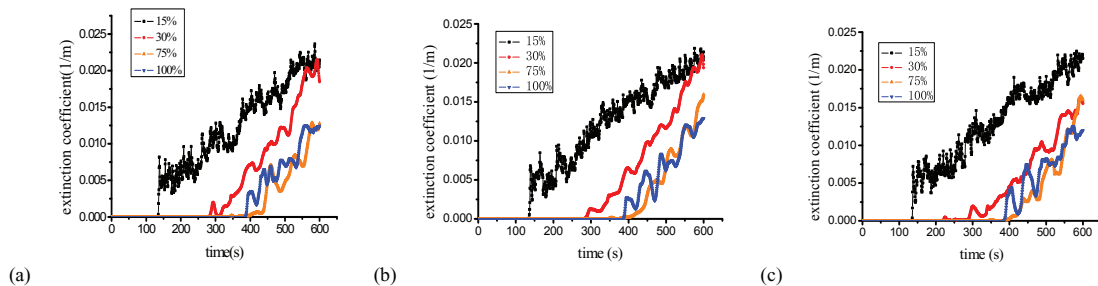


Fig. 7. Extinction coefficient curve below suspended ceiling in different hollowing conditions for (a) 21#, (b) 24# and (c) 28#.

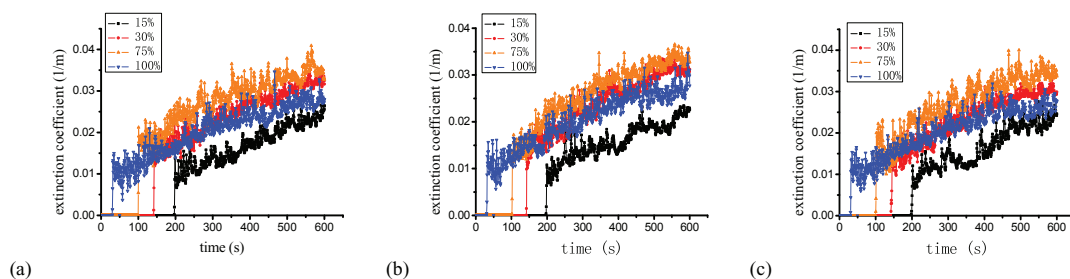


Fig. 8. Extinction coefficient curve below building roof in different hollowing conditions for (a) 1#, (b) 4# and (c) 8#.

Testing dots on the same locality below building roof and suspended ceiling in the same condition of the hollowing rate form a group. The extinction coefficient curve of two groups in the condition of 15%, 30% and 75% hollowing rate are shown in Fig 9. It shows that on the same locality, the testing dot of 15% hollowing rate below suspended ceiling detects earliest smoke; the testing dots of 30% hollowing rate below suspended ceiling and below building roof detect smoke approximately at the same time, and the time below building roof is earlier; the detecting time of 75% hollowing rate below suspended ceiling is distinctly earlier than that below building roof. In addition, in the same condition of the time and the hollowing rate, we can see the extinction coefficient of 24# testing dot on 15% hollowing rate is larger than that of 4#; on 30% hollowing rate, the extinction coefficient of 4# testing dot is a little larger than that of 24#; on 75% hollowing rate, the extinction coefficient of 4# testing dot is much larger than that of 24#. As the quantitative aspect, the extinction coefficient curve of each testing dots indicates the relationship between the law of smoke flow and the hollowing rate of grid ceilings.

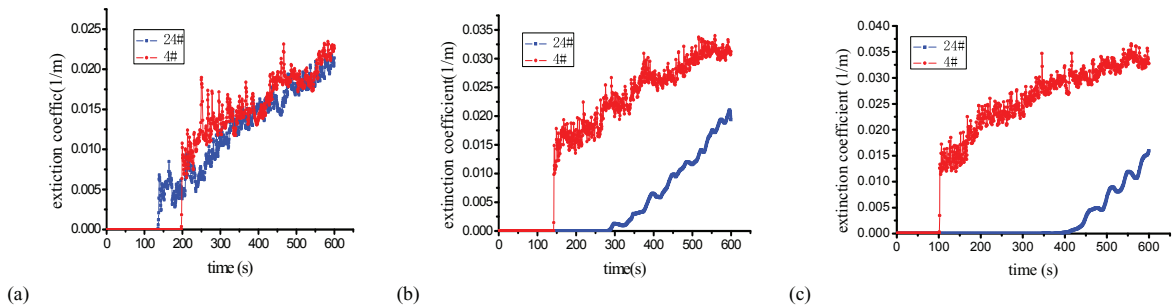


Fig. 9. 4# and 24# extinction coefficient curve for (a) 15%, (b) 30% and (c) 75% hollowing rate.

### 3. Response experiment of different hollowing rate in grid suspended ceiling places

The grid suspended ceiling in 75 mm × 75 mm size is chosen to cover over the whole ceiling (10m × 7m) 1m away from the building roof, and the hollowing rate is changed by using different width of tapes to paste, as shown in Table 1 and Fig 10. Then different grid ceilings with the hollowing rate of 15%, 30% and 75% are obtained, and without grid ceiling is equal to 100% hollowing rate. The detectors of testing dots (16 in all) locate at the same place in numerical simulation between the grid ceiling and the building roof. According to the related requirement of point-type smoke fire detectors in GB4715-2005<sup>[3]</sup>, the fire source in the experiment should use the smoldering fire of SH1.

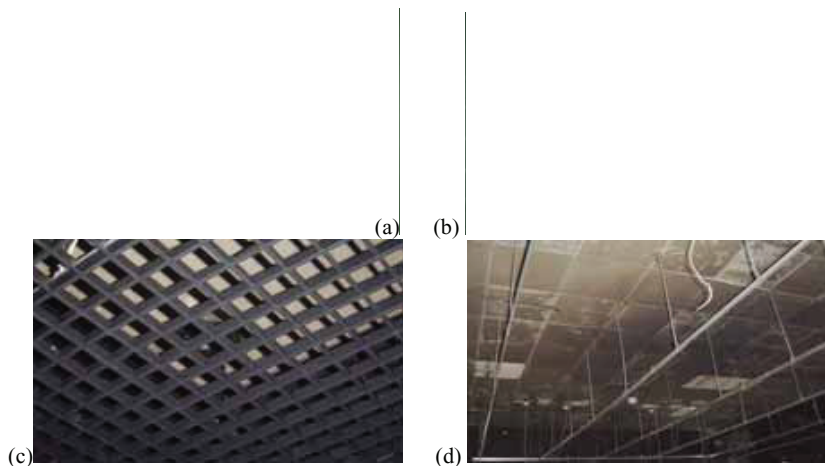


Fig. 10. The experiment grid suspended ceiling in (a) 15%, (b) 30%, (c) 75% and (d) 100% hollowing conditions.

The smoke development above and below grid ceiling at the time of 300s under the hollowing rate of 15%, 30% and 75% are shown in Fig 11 and Fig 12. From the figures it is clear to see that: with the decreasing of the hollowing rate, the smoke concentration below the grid ceiling gradually increases while at the same time gradually decreases above the grid ceiling. In the early stage of smoke spread, it is easy to rise, so there is hardly any smoke below the grid ceiling when the hollowing rate is 30% or 75%, then the smoke spread toward the building roof through the ceilings. However, when the hollowing rate reduces, the smoke would come across obstacles. Some will spread



below the grid ceiling and then gradually form a smoke layer. And when the hollowing rate is 15%, the smoke concentration below the grid ceiling will be slightly larger because of the smaller hollowing area, and the smoke concentration above will be smaller correspondingly.

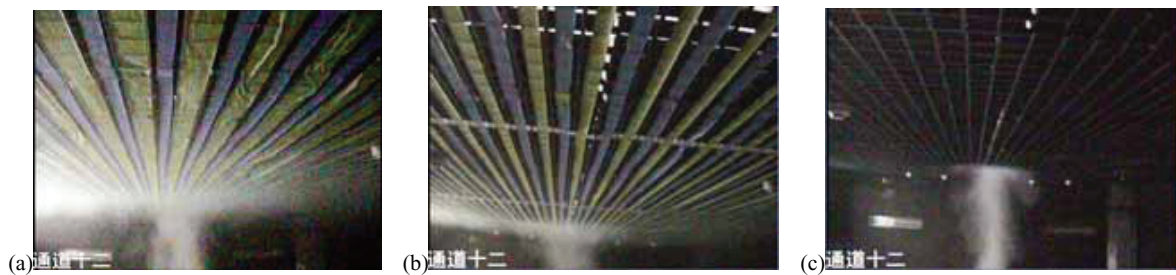


Fig. 11. The flow of smoke in (a) 15%, (b) 30% and (c) 75% hollowing conditions of lower grid suspended ceiling at the time of 300s.



Fig. 12. The flow of smoke in (a) 15%, (b) 30% and (c) 75% hollowing conditions of upper grid suspended ceiling at the time of 300s.

The smoke concentration in the combustion chamber ceiling, which is in the condition of no grid suspended ceiling, is shown in Fig 13. Because there is no obstacle, the smoke rises in the form of regular columnar and diffuses gradually in the building roof, spreading along the horizon and uniformly to every direction. At the same time, the smoke rise rapidly and reach to a higher concentration in 60s.

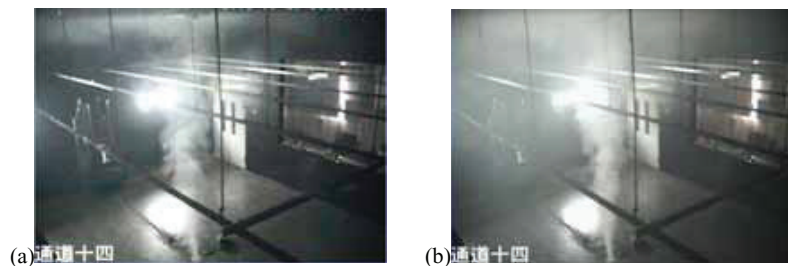


Fig. 13. The flow of smoke in (a) 120s and (b) 180s for no grid suspended ceiling place.

The experiment would finish after all the detectors alarm under every hollowing rate. Every detector's response time in three conditions of hollowing rate is recorded by the alarming manipulator. Fill the response time of the detector samples above (1#-8#) and below (21#-28#) the grid ceiling in the data sheet. Table 2 and Table 3 are as follows.

Table 2. The detectors' response time table above the grid suspended ceiling in different hollowing conditions

Hollowing	Detectors							
	1#	2#	3#	4#	5#	6#	7#	8#
15%	7'36''	5'52''	5'16''	3'48''	5'25''	6'16''	7'12''	6'36''
30%	3'24''	4'49''	5'02''	4'49''	4'28''	4'24''	3'52''	4'53''
75%	3'16''	3'16''	3'20''	3'07''	3'25''	3'25''	3'12''	6'30''

Table 3. The detectors' response time table below the grid suspended ceiling in different hollowing conditions

Hollowing	Detectors							
	21#	22#	23#	24#	25#	26#	27#	28#
15%	2'40''	3'43''	3'24''	3'20''	3'28''	3'44''	4'05''	4'06''
30%	5'26''	9'19''	7'05''	4'45''	4'36''	5'10''	10'11''	8'08''
75%	13'56''	16'22''	13'56''	22'44''	29'22''	26'02''	17'33''	13'51''

The response time of the detectors above the grid suspended ceiling decrease with the increase of the hollowing rate. On the other hand, the response times are pretty much the same value, especially in the condition of the hollowing rate of 75%.

If eliminate the maximum, the differences of the response times are smaller. It is because that the grids of 75mm×75mm have the height of 40mm. In that case, the grids work as the function of chimney effect, making the smoke spread to the building roof when the smoke reaches the grid ceiling. Because the ceiling is smooth, whether the hollowing rate is large or small, the smoke can spread along the ceiling well if only the smoke could penetrate the hollowing. When the hollowing rate is large, the smoke can spread successfully at the ceiling. So the response times of the detectors in the building roof are equal, having small differences.

The response times of the detectors below the grid suspended ceiling increase with the increase of the hollowing rate. On the other hand, at 15% hollowing rate, there is an undersized difference of these response times; the phenomenon indicates that the smoke spread well along the grid suspended ceiling and makes the detectors response gradually. Increasing with the hollowing rate, the response time appears to follow a discontinued trend. At 30% hollowing rate, smoke turns to accumulate above the grid suspended ceiling and then gather below it through permeation instead of spreading well along the suspended ceiling. At 75% hollowing rate, the response time of the detectors under the suspended ceiling are much longer than those of other hollowing rates. The comparison of experimental results, of the condition without grid suspended ceiling and of the condition with the highest hollowing rate, is shown in Table 4.

Table 4. The comparison table of experimental results between 75% hollowing rate and 100% hollowing rate

Hollowing	Detectors								Average response time
	1#	2#	3#	4#	5#	6#	7#	8#	
75%	3'16''	3'16''	3'20''	3'07''	3'25''	3'25''	3'12''	6'30''	3'41''
	2'24''	2'32''	2'04''	1'39''	2'45''	2'57''	2'24''	1'52''	2'20''
100%	2'30''	2'22''	2'43''	2'51''	2'55''	3'08''	2'30''	2'31''	2'41''

At 75% hollowing rate, the average response time of detectors above the suspended ceiling is 3'41", which is shorter than the condition without suspended ceiling for about one minute. The result indicates that the existence of suspended ceiling does affect the response of detectors no matter the span of hollowing rate. Meanwhile, in a condition without suspended ceiling, the paper replaces detectors 1-8# with 21-28# and finds that the difference of average response times of two groups is 19 seconds, which is a good uniformity. And it indicates that the detectors used in previous experiments are of indifference themselves, the difference in property of response is completely depending on the hollowing rate.

The response time of three different hollowing rates and the difference of average response time above and below the suspended ceiling are shown in Table 5.

Table 5. The detectors' response instance of lower and upper grid suspended ceiling on different hollowing conditions

Hollowing	Response instance		Average response time
	In a group	Not in a group	
15%	All of lower detectors alarm first	All of lower detectors alarm first	2'21''
30%	One group of lower detectors alarm first, seven groups of upper detectors alarm first	Response between lower and upper detectors	2'33''
75%	All of upper detectors alarm first	All of upper detectors alarm first	15'10''

According to the experimental results, at 30% hollowing rate, detector 25# and 24# below the grid suspended ceiling responses faster than the slowest 3# above the suspended ceiling for just 26 seconds and 17 seconds, regardless of position. Hence, we consider that at a hollowing rate larger than 30%, the detectors above the grid suspended ceiling response faster than those below.

According to the related requirement about the fire parameters of the experiments in GB4715-2005, there is no flame in experimental woods before each group's termination or the detectors' response. We can get the quantity of  $m$  and  $y$  according to the system and press the "validity" button to check the validity curve of SH1. As curve  $m-t$  and curve  $m-y$  of each group meets the requirement in appendix of GB4715-2005, the validity of SH1 is confirmed.

#### 4. Conclusions

It's shown by the study that different hollowing rate in grid suspended ceilings has different validity of photoelectric smoke fire detectors, there is a hollowing rate range of grid suspended ceilings which should based on the real experiment results to make sure the suitable place of the fire detector installation. When the hollowing rate is less than the minimum of the hollowing rate range, detectors installed under the grid suspended ceilings would be sounded first. When the hollowing rate is more than the maximum of the hollowing rate range, detectors installed above the grid suspended ceilings would be sounded first; in the range of the minimum and maximum, we should base on the experiment results to make sure the suitable installation places. The model is proved correct by comparing simulation and test results.

#### References

- [1] United States standard: National Fire Alarm Code, NFPA72-2007.
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